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Global Warming: A Science Overview for the A/C Industry

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Introduction: Fossil fuels (i.e., coal, oil, and natural gas) provide about 85% of the world's energy, sustaining our standard-of-living. They are inexpensive, transportable, safe, and relatively abundant. At the same time, their use contributes to problems such as air quality and acid rain that are being addressed through various control efforts and to the problem of global warming, which is now being considered by governments of the world. This talk will focus on six key aspects of the scientific findings that are leading to proposals for significant limitation of the emissions of fossil-fuel-derived carbon dioxide and limitations on emissions of other greenhouse gases that can influence the global climate, including substances used in the refrigeration and air-conditioning industries.

1. **Human Activities are Changing Atmospheric Composition, and in Particular are Increasing the Concentrations of Radiatively Active (Greenhouse) Gases and Particles:** Observations from global measurement stations and reconstructions of the composition of the atmosphere in the past clearly indicate that human activities are increasing the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and of various halocarbons (HCFCs and, until very recently, CFCs), collectively referred to as greenhouse gases because of their warming influence on the climate. The history of emissions versus concentrations, analyses of carbon isotopes, and other means all make clear that these changes are occurring as a result of human activities rather than because of natural processes. The CO_2 concentration of almost 370 parts per million by volume (ppmv) is now about 30% above its preindustrial value of about 280 ppmv and the CH_4 concentration is up over 150%. While these gases occur naturally, records going back many thousands of years indicate the present levels are well above natural levels. The concentrations of many halocarbons are entirely new to the atmosphere—many of these compounds are solely a result of human activities. The lifetime of the excess contributions of these gases in the atmosphere ranges from decades (for CH_4) to centuries (for CO_2 and some halocarbons) to thousands of years (for some perfluorocarbons). Human activities are also contributing to an increase in the concentrations of small particles (called aerosols) in the atmosphere, primarily as a result of emission of sulfur dioxide (SO_2) from coal combustion; once in the atmosphere, SO_2 is transformed into sulfate aerosols which create the whitish haze common over and downwind of so many industrialized areas. This haze tends to exert a cooling influence on the climate. Of critical importance is that the typical lifetime of aerosols in the atmosphere is less than 10 days (they are rained out as acid rain), so it is hard for global concentrations to build up very much. Although natural processes can also affect the concentrations of gases and aerosols, these have been in quite good balance over the past 10,000 years, and it is human activities that are now changing atmospheric composition in ways that are exceeding the capability of natural processes to maintain the balance.

2. **Increasing the Concentrations of Greenhouse Gases Will Warm the Planet and Change the Climate:** From laboratory experiments, from study of planetary atmospheres, from observations and study of energy fluxes in the current atmosphere, and from reconstructions of past climatic changes and their causes, it is very clear that the concentrations of key greenhouse gases play a very important role in determining the surface temperature of the Earth. Of the solar radiation reaching the top of the atmosphere, about 30% is reflected (lost) back into space by the atmosphere (primarily by clouds) and the surface; about 20% is absorbed in the atmosphere (primarily by water vapor, clouds, and aerosols), and about 50% is absorbed at the surface. As for all systems, energy absorbed is then radiated away as heat (infrared radiation) based on the temperature of the object. Were the Earth's surface and atmosphere a simple radiator with the reflectivity of the present Earth, the average temperature would be very near 0°F. However, as heat is radiated from the surface, most of it is absorbed by the greenhouse gases in the atmosphere. A significant fraction of the energy is then radiated back to the surface, causing warming of the surface and more radiation to be radiated upward and absorbed, providing more energy to be radiated back to the surface. Less

than 10% of the energy radiated from the surface gets through directly to space without being absorbed. An additional warming influence results because the atmospheric temperature decreases with altitude up to the tropopause (about 8-10 miles up) before temperatures start to rise again in the stratosphere due to solar absorption by ozone. As more greenhouse gases are added, the absorption and back radiation to the surface comes from lower and warmer layers in the atmosphere, strengthening the greenhouse effect. The greenhouse effect of the gases already mentioned is exceeded by the greenhouse effect of water, which is transported into the atmosphere through evaporation at the surface (and the warmer the surface temperature, the more water vapor is lofted into the atmosphere). The water vapor condenses, which leads to formation of clouds; the condensation also releases heat into the atmosphere that is radiated both upwards and downwards, amplifying the greenhouse effect. Clouds both reflect solar radiation to space (so exert a cooling influence) and absorb upcoming and reradiate downward-directed infrared radiation, creating a warming influence. Together, the natural greenhouse effect raises the average surface temperature of the Earth from about 0°F to almost 60°F. Quite clearly, if we add greenhouse gases to the atmosphere, we will tend to warm the average temperature. While aerosols exert a cooling influence, it would take an unrealistically large amount of aerosols to cause global cooling instead of warming.

3. **Increases in the Concentrations of Greenhouse Gases Since the Start of the Industrial Revolution are Already Changing the Climate, Including Warming the Earth:** With the evidence indicating that the concentrations of greenhouse gases have risen significantly since the start of the Industrial Revolution and with the expectation that increasing the concentrations of greenhouse gases will cause warming, a key test of our understanding is to see if changes are already occurring as a result of past emissions and if they are about of the magnitude that we would expect. Instrumental records of temperature for large areas of the Earth go back to the mid-19th century, and these records show a warming of over 1°F over this period. Extensive proxy records (i.e., records derived from tree rings, ice cores, coral growth, etc.) for the Northern Hemisphere going back about 1000 years also indicate very significant warming this century compared to the natural variations over earlier centuries that were likely caused by natural variations in solar radiation and the occasional eruption of volcanoes. That warming is occurring is also confirmed by rising temperatures measured in boreholes (i.e., dry wells), retreating mountain glaciers and sea ice, increasing concentrations of atmospheric water vapor, rising sea level due to melting of mountain glaciers and thermal expansion in response to recent warming (augmenting the natural rise due to the long-term melting of parts of Antarctica), and related changes in other variables. The key question is whether these changes might be a natural fluctuation or whether human activity is playing a significant role. Among the reasons that the effect is being attributed largely to human activities is the coincidence in timing with the changes in greenhouse gas concentrations, the very large and unusual magnitude of the change compared to past natural fluctuations, the warming of the lower atmosphere and cooling of the upper atmosphere (a sign of a change in greenhouse gas concentrations rather than in solar radiation), and the global pattern of warming. Some uncertainty is introduced because some of the warming occurred before the sharpest rise in greenhouse gas concentrations (probably due to an increase in solar radiation contributing to some of the earlier warming) and to the rise in tropospheric temperatures being a bit slower than the rise in surface temperatures over the past two decades (apparently a result of the confounding influences of ozone depletion, volcanic eruptions, and El Nino events). In summary, however, the Intergovernmental Panel on Climate Change (IPCC) concluded that "The balance of evidence suggests a discernible human influence on the global climate," concluding, in essence, that the evidence meets the criterion for a civil rather than a criminal conviction. Since their 1995 report, the evidence has grown considerably stronger, more clearly indicating that the magnitude and timing of the warming quite closely match what would be expected from the combined influences of human and known natural influences.

4. **Future Emissions of Greenhouse Gases and Aerosols Will Lead to Significant Climate Change, Including Much More Warming and Sea Level Rise, Over the Next Century (and Beyond):** With 6 billion people on the planet and current average fossil fuel use, each person is responsible, on average, for emission of 1 metric ton of carbon (or about 2.75 tons of CO_2) per year. Per capita use varies widely across the world, reaching over 5 tons per year in the US but amounting to only about 0.5 ton per person per year in developing countries. Projections for the year 2100 are that global population will increase to perhaps 8 to 10 billion, and that, without emissions limits, average per capita emissions across the globe may double as fossil fuel use grows significantly in the highly populated developing nations. If this happens, total annual emissions would more than triple from about 6 billion tons per year to about 20 billion tons of carbon per year. This would raise the atmospheric CO_2 concentration to just over 700 ppmv (or almost double its present value), or over 250% above its preindustrial value. Projections based on the types of past changes

that have occurred, on theoretical analyses, on understanding of planetary atmospheres, on extrapolation of recent trends, and, especially, from numerical climate models all suggest that this will lead to significant future warming. The 1995 IPCC assessment projected a global warming ranging from about 2 to over 6°F if we do not control emissions of SO_2 and up to about 8°F if developing nations do control SO_2 emissions as we have (a step that seems necessary for health-related reasons). Quite certainly, we will be experiencing warming over the next several decades, even were we to sharply reduce emissions. Associated with this warming would be shifts in precipitation zones, intensification of evaporation and precipitation cycles (that are often associated with extremes of floods, droughts, and storms), and a significant acceleration in the rate of sea level rise. That there could be surprises is also recognized, with potential thresholds and non-linearities likely hiding somewhere (as was the case for the Antarctic ozone hole). Among the possibilities are potential disruption of the Gulf Stream and the larger scale deep ocean circulation of which it is a part, weakening of which apparently occurred coming out of the last glacial about 11,000 years ago and led to a strong, but mainly regional, cooling over Europe.

5. **The Consequences of Climate Change Seem Likely to be Diverse and Distributed, with Benefits for Some, Damages to Others, and All Somewhat Uncertain:** With fossil fuels providing so many benefits, contemplating changes in the ways in which we derive and use energy would seem appropriate only if the types of consequences with which we will need to cope and adapt are also quite significant. Several types of consequences have been identified and are being evaluated[1]:
   - Human health: Sharp increases in summertime heat index may increase mortality unless offset by much more extensive air-conditioning; more poleward spread of mosquitoes and other disease vectors may increase the incidence of infectious disease unless managed by public health and building design measures; increased intensity of extreme events may injure or kill more people (and disrupt communities) without more risk-adverse planning and construction.
   - Food supplies: Increased CO2 will aid growth of many crops and improve their water use efficiency. If this happens widely (i.e., if other constraints on agriculture do not arise), crop production should rise, increasing overall commodity supplies, and reducing food costs for the public. For the farmer, lower commodity prices will stress farm income, and farmers in marginal areas, even though benefiting from some production gain, are unlikely to remain competitive, causing economic problems in related rural communities unless other profitable crops are identified.
   - Water supplies: Changes in the location and timing of storms will alter runoff timing and amount, requiring changes in how water management systems are operated. This will be especially the case in the western US because there will likely be less snow and more rain in winter coupled with more and earlier melting of snow; these changes will likely require a lowering of reservoir levels in winter to ensure a flood safety margin even though this risks reducing water availability in summer when demand will be rising. Increased summertime evaporation may also diminish groundwater recharge in the Great Plains and reduce levels of the Great Lakes and the runoff in rivers such as the Mississippi, stressing water transportation and recreation.
   - Fiber and services from forests and grasslands: While winter precipitation may increase, warmer temperatures will significantly increase, thus likely reducing available summertime soil moisture. Some, but not all, of these effects may be offset by the increased CO_2 concentration. As the seasonal temperature and soil moisture change, ecosystems will be affected, with changes in tree and grass types and then associated changes in wildlife. As regions accumulate carbon in vegetation and dry up, fire risk increases. Some climate model projections suggest a much drier southeastern US, stressing the current forests; at the same time, the southwestern deserts may get wetter and sprout more vegetation. What is most important to understand is that the notion of ecosystem migration is a misconception—particular species will indeed grow in different locations, but this will likely mean the tearing apart of existing ecosystems and the creation of new ones, albeit not with the time for much adjustment, adaptation, and evolution to take place. Changes over the next 100 years may be as great as over the last 10,000 years.
   - Coastal endangerment: Mid-range projections suggest that the relatively slow rate of rise of sea level this century (about 4 to 10 inches, reduced or amplified by regional changes) may increase by a factor of 3. For regions currently subsiding (e.g. Louisiana, the Chesapeake Bay, etc.), there could

[1] The National Assessment of the Potential Consequences of Climate Variability and Change for the United States, which is currently under review, will summarize impacts at the national level (see http:// www.nacc.usgcrp.gov). The Intergovernmental Panel on Climate Change is currently preparing its Third Assessment Report, (http://www.usgcrp.gov/ipcc), which will summarize scientific findings on all aspects of the climate change issue.

be a significant acceleration in coastal loss, especially of natural areas such as wetlands and other breeding grounds where protective measures cannot be afforded. The concern is greatest during coastal storms when storm surges (and therefore damage) will reach further inland and further up rivers and estuaries. For developed areas, strengthening of coastal protection is needed, not just to protect against sea level rise, but also to reduce current vulnerability to coastal storms and hurricanes.

- International coupling: While it is natural to look most intently at consequences locally, we are intimately coupled to the world in many ways. What happens outside the US will affect our markets, our overseas investments, the availability of food and other resources that we import, and the global environment that we all share. Health-related impacts overseas will affect us as travelers come to the US and as US citizens travel abroad for business and pleasure. Many resources, from water and hydropower-derived electricity to fisheries and migrating species, are shared across borders, move or are transferred internationally. Finally, we are a largely a nation of immigrants, and when disaster strikes overseas, we respond with resources and often by taking in refugees. We are clearly connected to what happens outside our borders.

It is very difficult to definitively define the risk and importance of these impacts to us or to quantify these impacts in a way that allows comparison with taking actions to change our energy system. At the international level, this becomes even more difficult, especially as cultural values enter the consideration (e.g., what is the present value of the risk of the Marshall Islands being flooded over in 50 to 100 years?). Overall, what can be said is that there will likely be important consequences, some negative and some positive; that we are only starting to understand what they may be; and that the present tendency to average across large domains can cover over rather large consequences for smaller groups.

6. **Reducing the Rate of Change of Atmospheric Composition in order to Slow Climate Change Will Require Significant and Long-lasting Cutbacks in Emissions:** In recognition of the potential for significant change, the nations of the world in 1992 agreed to the Framework Convention on Climate Change, which set the objective of "stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" but doing so in a way that would "allow ecosystems to adapt naturally to climate change, ... ensure that food production is not threatened, and ... enable economic development to proceed in a sustainable manner." Both defining the terms and accomplishing the objective is a formidable challenge. Stabilizing the atmospheric concentration at double the preindustrial level (so about 550 ppmv) would require stabilization of the present per capita CO_2 emission level at about 1 ton per person per year rather than allowing it to double over the next century as it is projected to do without controls (and remember the US is at 5, Europe at 3, and the developing world at 0.5). Then, for the 22nd century, emissions would need to drop by at least a factor of 2. Even though the Kyoto Protocol is now quite controversial, it would be only a rather modest start in this direction. Achieving even the projected levels of emissions will require significant introduction of non-fossil energy technologies, improvement in efficiencies, and switching to natural gas from coal (or even worse from a CO_2 emissions standpoint, oil-shale-derived energy). What is clear from present energy analyses is that there is no "silver bullet" that can accomplish all of the changes; what would be required over the next century is a rather aggressive (but not unprecedented) rate of improvement in energy efficiency, broad-based use of non-fossil technologies (often selecting based on local resources and climatic conditions), and accelerated technology development and implementation.

Conclusion: A major reason for controversy about dealing with this issue results from differing perspectives about how to weigh the need for scientific certainty, about ensuring a reliable source of energy to sustain and improve the national and global standard-of-living, about capabilities for improving efficiency and developing new technologies, about the risk to "Spaceship Earth" being imposed by this inadvertent and virtually irreversible geophysical experiment, about the economic costs and benefits of taking early actions to reduce emissions (including what factors to consider in the analysis and how to weight the importance of long-term potential impacts versus better defined near-term costs), and about the weight to give matters of equity involving costs and impacts for rich versus poor, the US versus other nations, and current generations versus future generations. I believe that coming to a consensus on this will require that we all become better informed and that the political system focus on finding approaches that tend to balance and reconcile these (and additional) diverse, yet simultaneously legitimate, concerns.

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